Exploring the Impact of Tropical Cyclone Relocation for the Operational NCEP GFS/GDAS

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Background & Motivation

- Continued improvement in TC track and intensity guidance important due to high societal impact

- Resolution and complexity of global numerical models continues to increase, making vortex initialization ever more important
  - Complicated by fact that few observations within TC region are assimilated
    - Representativeness, scattering (clouds/precipitation), etc.

- Process for initializing TCs in operational NWP suite is complicated and differs by modeling system
  - ***NCEP/EMC fields many questions about the process in the GFS/GDAS***

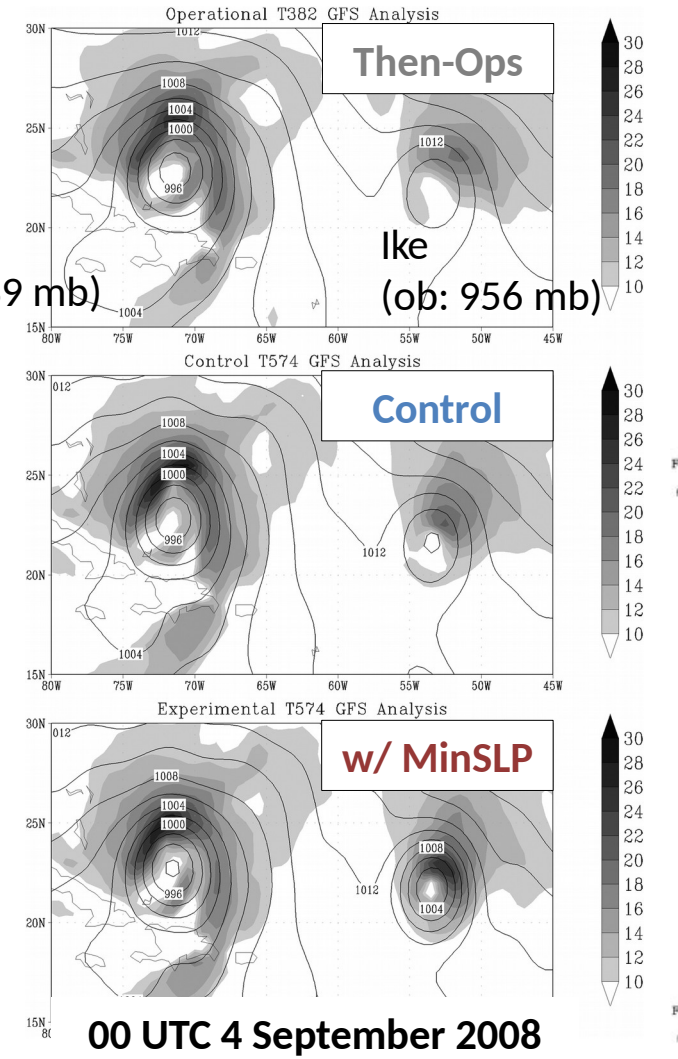
TC Initialization at NCEP

- For the operational GFS / GDAS, there is always some component from outside of the actual assimilation of real observations involved:

1. "Tracker" is run on GDAS forecast
   a. If storm found in forecast/background, ***mechanical relocation*** of vortex
   b. If not found, ***bogus observations*** are generated (winds are assimilated)

2. Advisory minimum sea-level pressure observations are then assimilated with other observations regardless of (1)

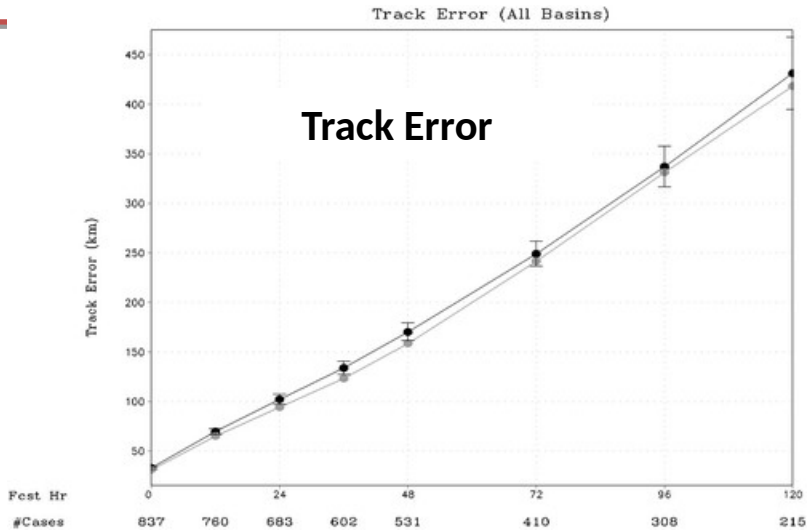
Advisory MinSLP in GDAS/GFS (Kleist 2011)



Hanna
(ob: 989 mb)

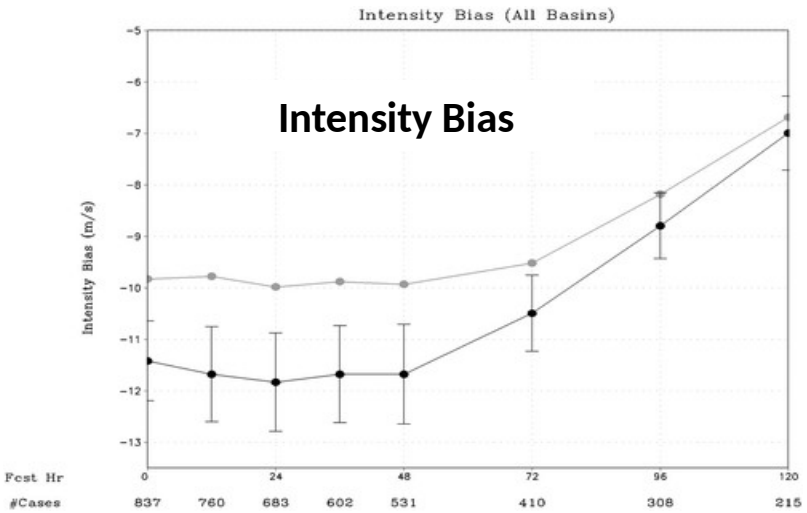
Ike
(ob: 956 mb)

00 UTC 4 September 2008



Control

MinSLP

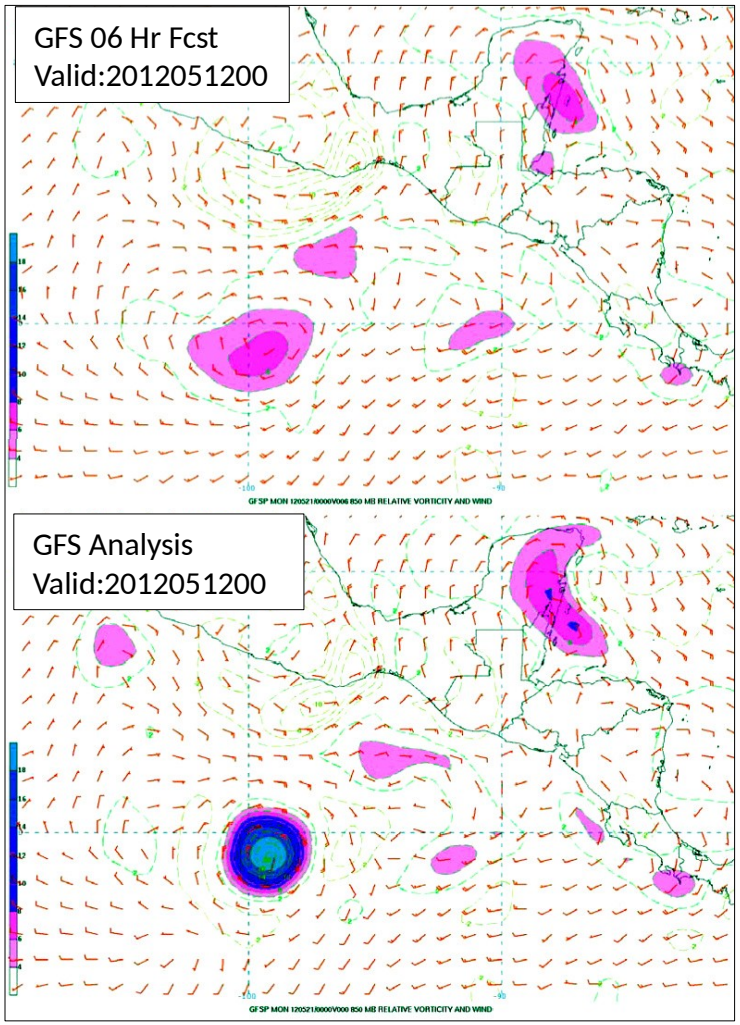


Control

MinSLP

Example of Bogus Wind Assimilation

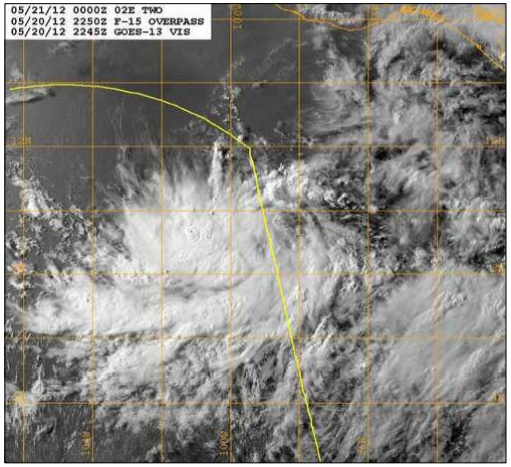
Generally rare in operations, Occurs mainly in genesis situation



Automated tracker "failed" to find coherent vortex to relocate

This can happen because:

- Distance from observation too large
- Too much tilt
- Parameters used to find position misaligned
- Nothing there



For Bud, tracker "failed" and resultant analysis had radically different vortex due to assimilation of bogus winds (and advisory minSLP)

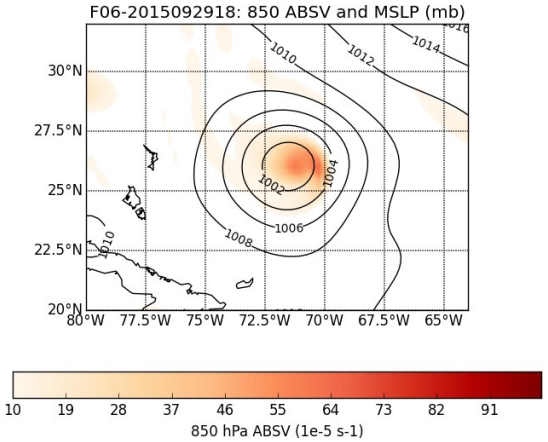
How does Mechanical Relocation Work?

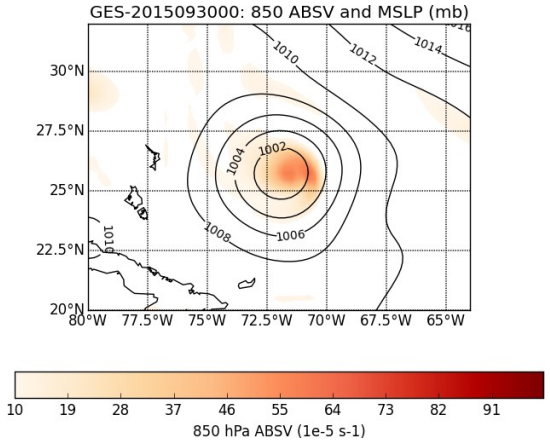
- Locate tropical cyclone vortex in short forecast/background
  - Automated tracker on post-processed regular grid (grib files)
  - Abort process if storm center over major land mass, if terrain >500m, or if relocation distance is too large
- Separate vortex from “environment” (GFDL Filter)
- Move vortex to advisory position
  - This then serves as background for assimilation
- Assimilate observations including advisory minSLP

Impact of Relocation on Joaquin (2015093000)

Move Storm SW by ~0.5 degrees

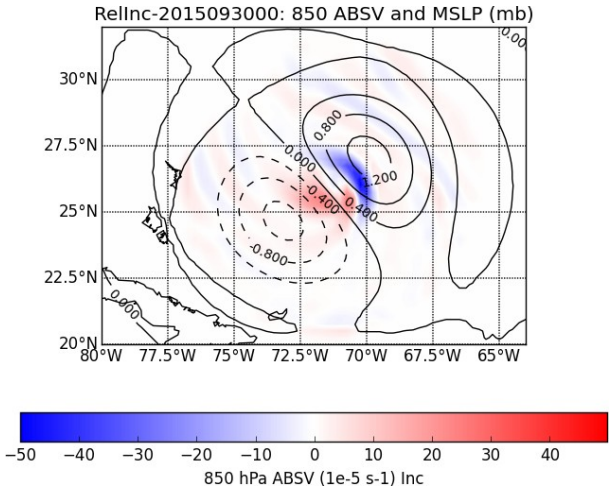
Original F06

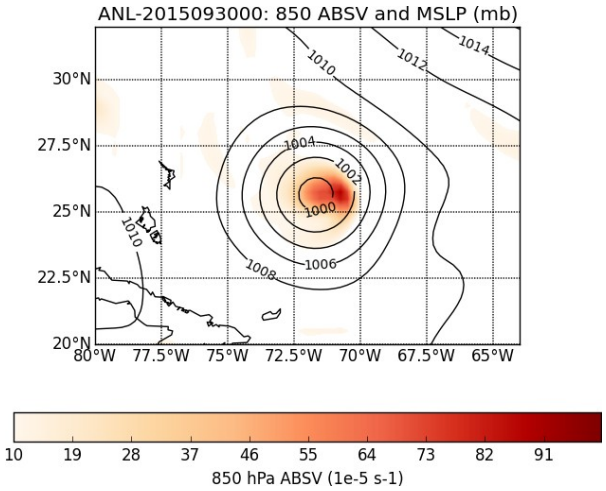




Relocated F06 (Background)

Relocation Increment





Final Analysis

Initial Motivation Came From 2012 Hybrid Initial Tests (small sample)

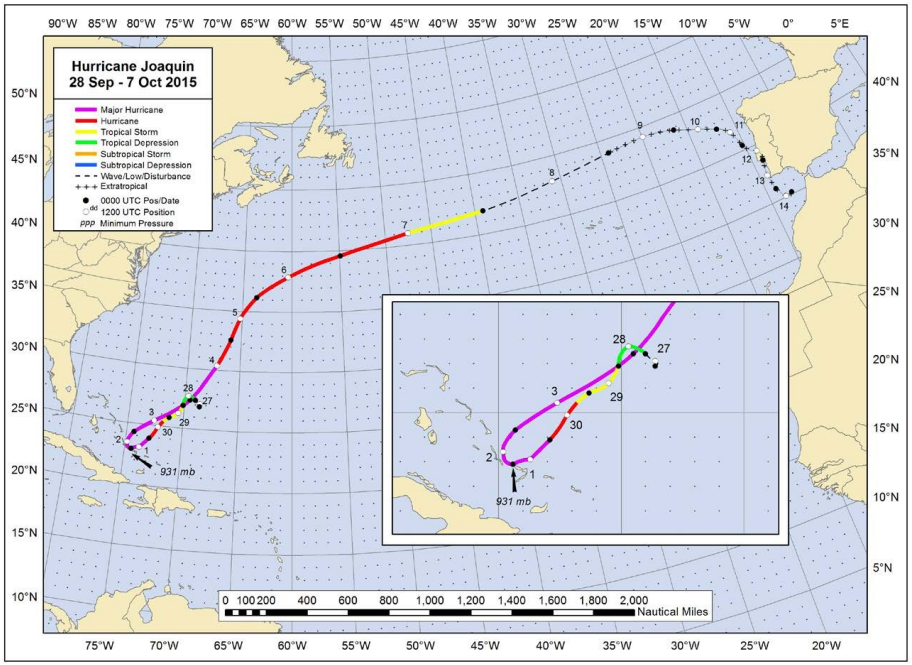
Mostly September Cases (AL 07-16, EP 10-12, WP 10-14):
average track errors (NM) FOR HOMOGENEOUS SAMPLE

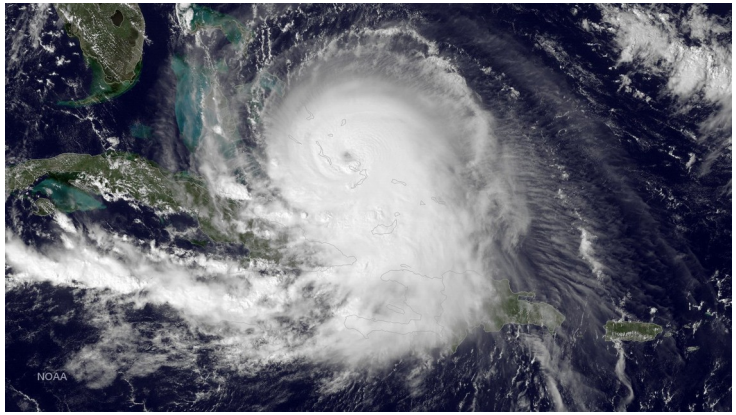
	00	12	24	36	48	72	96	120		
3DVAR(REL)		**18.4**	**33.1**	**50.2**	**70.1**	**83.5**	**124.0**		**171.6**	**195.1**
3DHYB(REL)		**17.5**	**33.0**	**46.9**	**60.3**	**72.4**	**113.7**		**175.1**	**186.5**
3DHYB(NO)		**22.9**	**32.7**	**43.6**	**59.7**	**68.6**	**108.6**		**159.0**	**177.7**
#CASES	73	67	58	49	42	30	24	17		

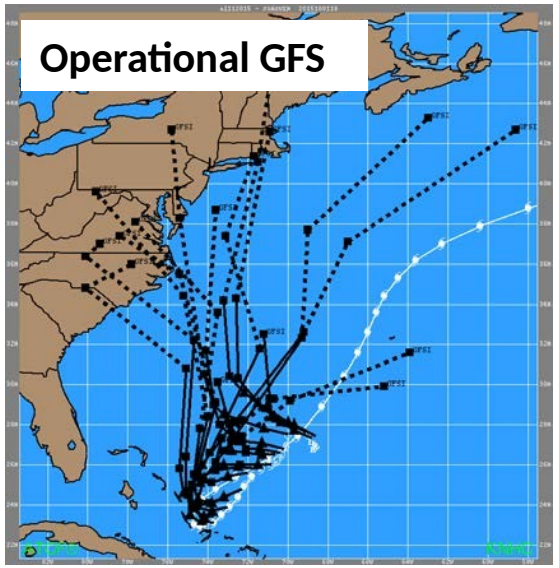
Experiments were initially run ***without* vortex relocation** (eventually turned back on and still operational).

Signs that mechanical vortex relocation in GFS hurts forecast despite seemingly better initial positions (compare red versus green beyond 12h).

Hurricane Joaquin (2015)







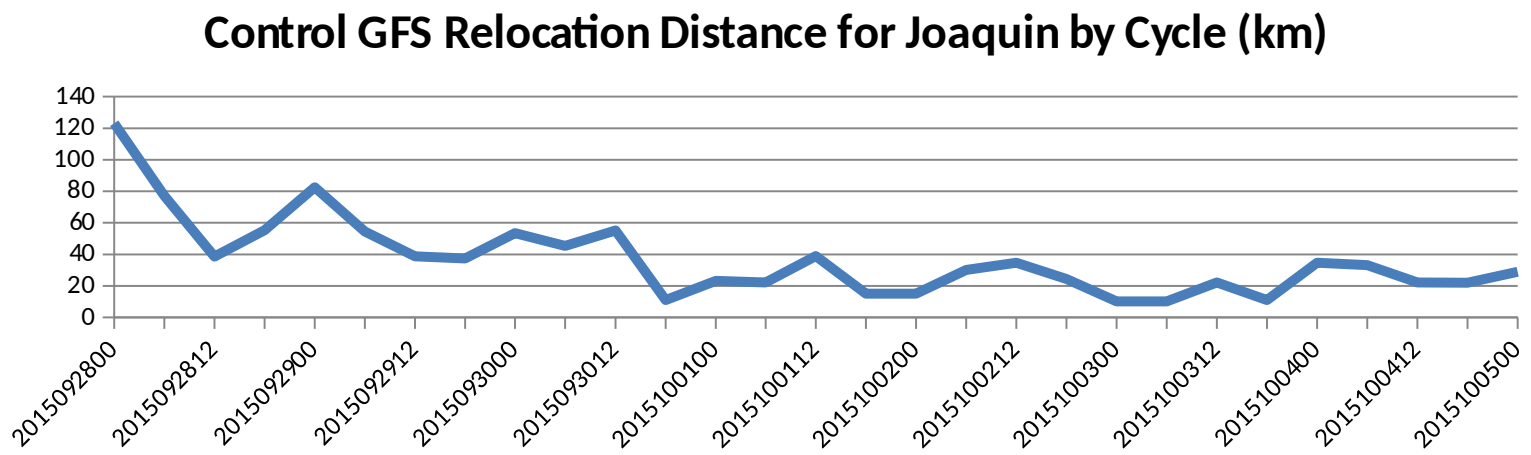
- High Impact in Bahamas
- Some guidance (GFS/HWRF) during early cycles advertised potential U.S. coastal impacts

Figures courtesy NHC TC Report

Joaquin (2015) Experiment

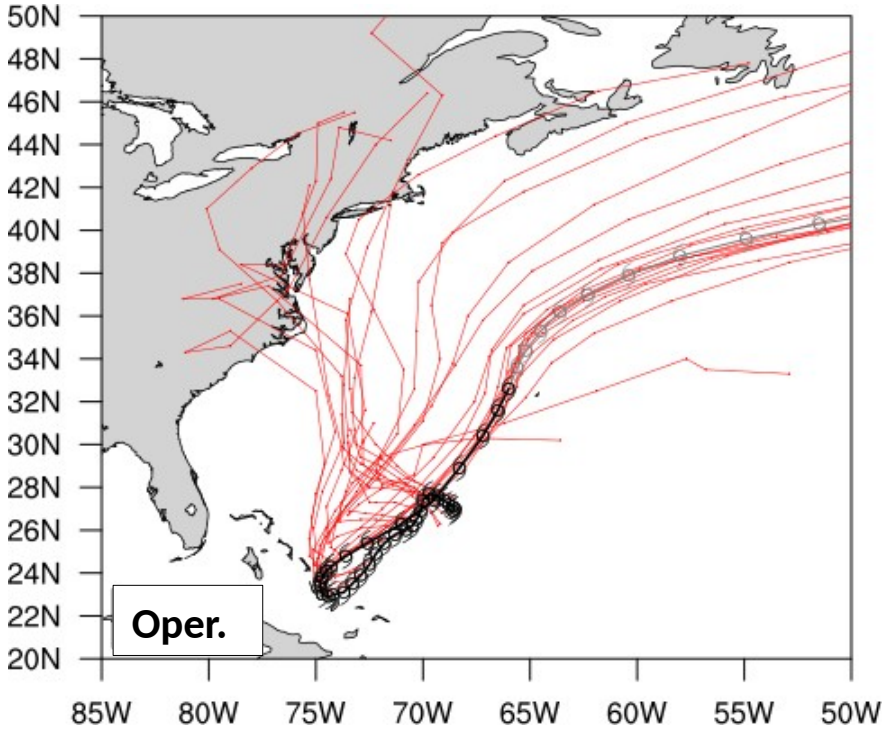
- Fully-cycled (early and late cut-off) T1534L64 GFS with 80 member EnKF-based ensemble for hybrid data assimilation (3D EnVar)
- Control (with relocation) and Experiment (without) started prior to classification of Joaquin as depression
  - For experiment without relocation the effect is cumulative – we are not evaluating the impact of relocation on any individual operational forecast
- Bogus winds were never generated in operations, control, or experiment
- Advisory MinSLP assimilated into hybrid and EnKF for control and experiment

Relocation in Control for Joaquin

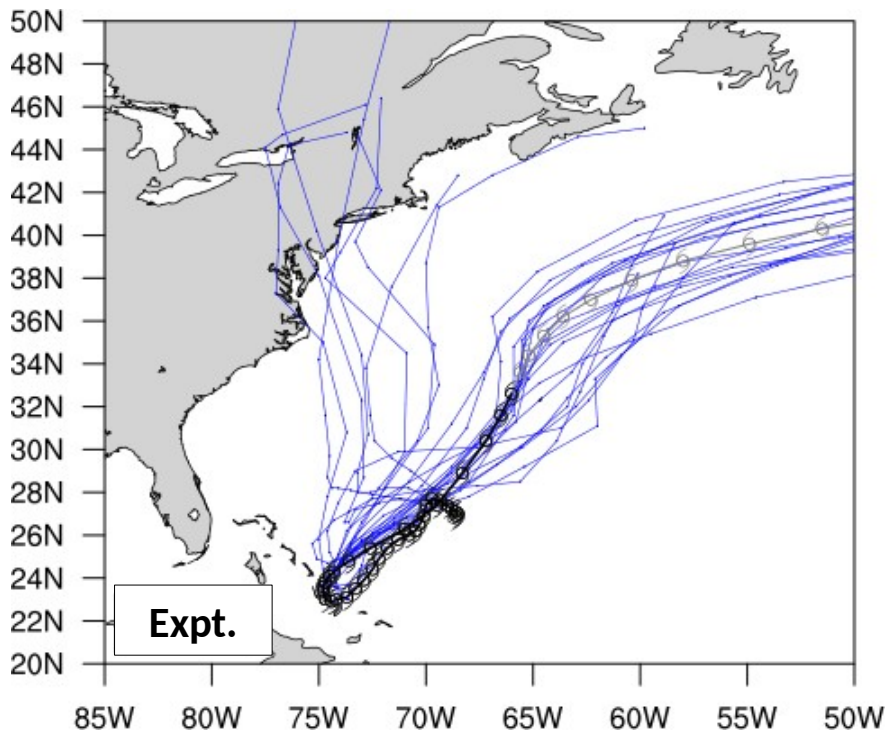


- During depression and TS phase, relocation distance larger than when storm reached hurricane status
- These are approximate – the tracker operates on quarter degree output and relocation is estimated to precision of tenths of degrees
- Also important to keep in mind that NHC analysis position has uncertainty about it as well

Track Summary for Experimental Period



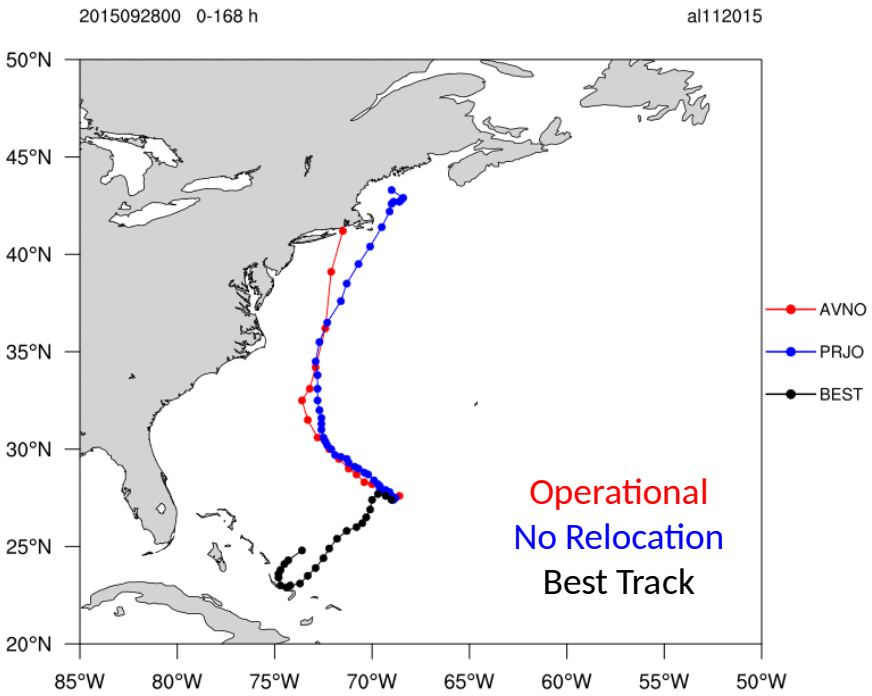
With Relocation



Without Relocation

Figures courtesy Andrew Penny/NHC

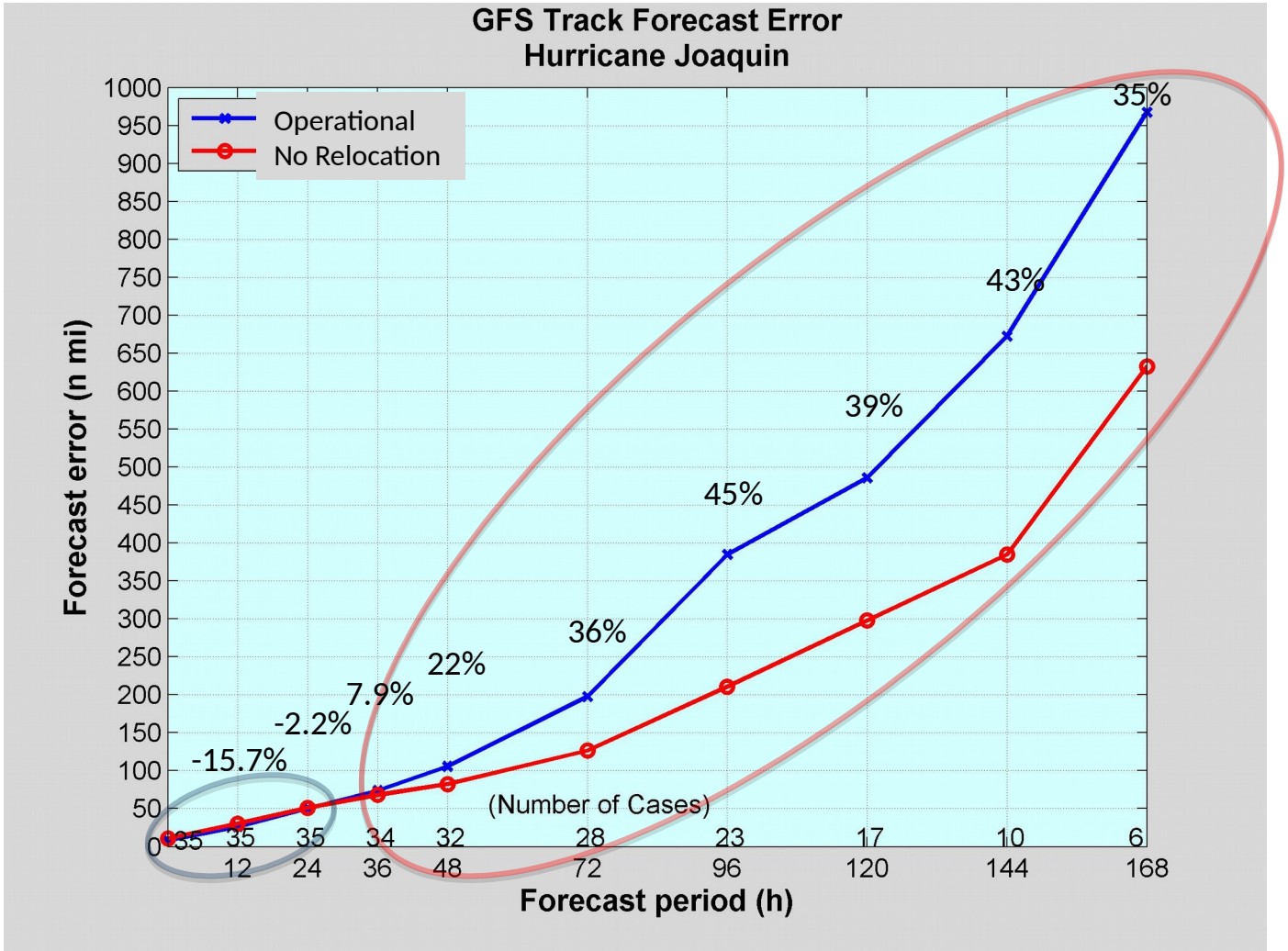
Joaquin Individual Tracks



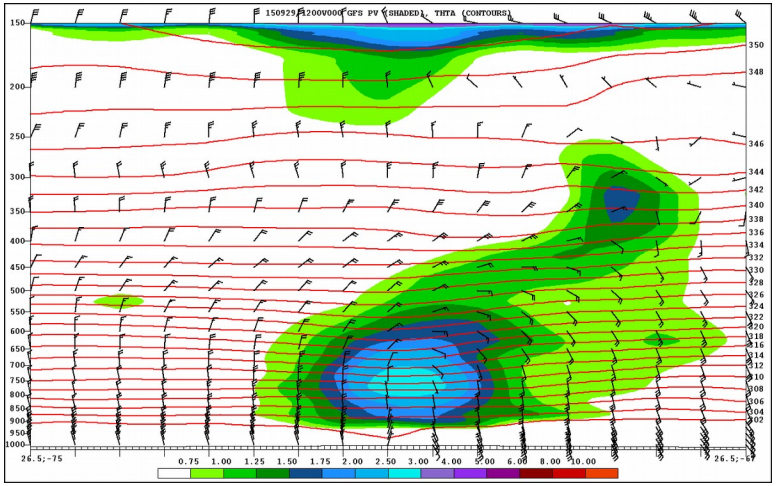
Figures courtesy Andy Penny/NHC

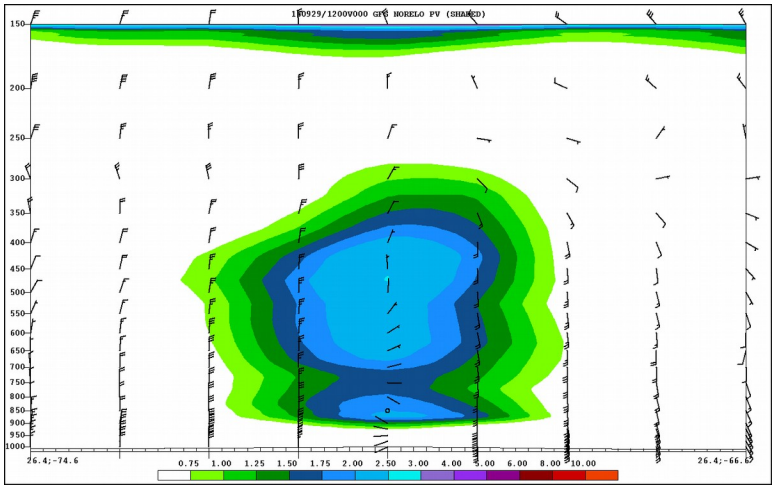
- ***No-relocation runs generally better beyond 24 hours***
- 093000-100200 – Forecast to 3 days better in no-relocation experiment
  - Captures initial SW track toward Bahamas that operational GFS does not
- 093000-100200 – Forecasts considerably better in no-relocation experiment
  - This despite slightly larger initial errors
  - 092918 exception as both bring storm to Carolina Coast
- 100206 and beyond – similar with NE track well predicted

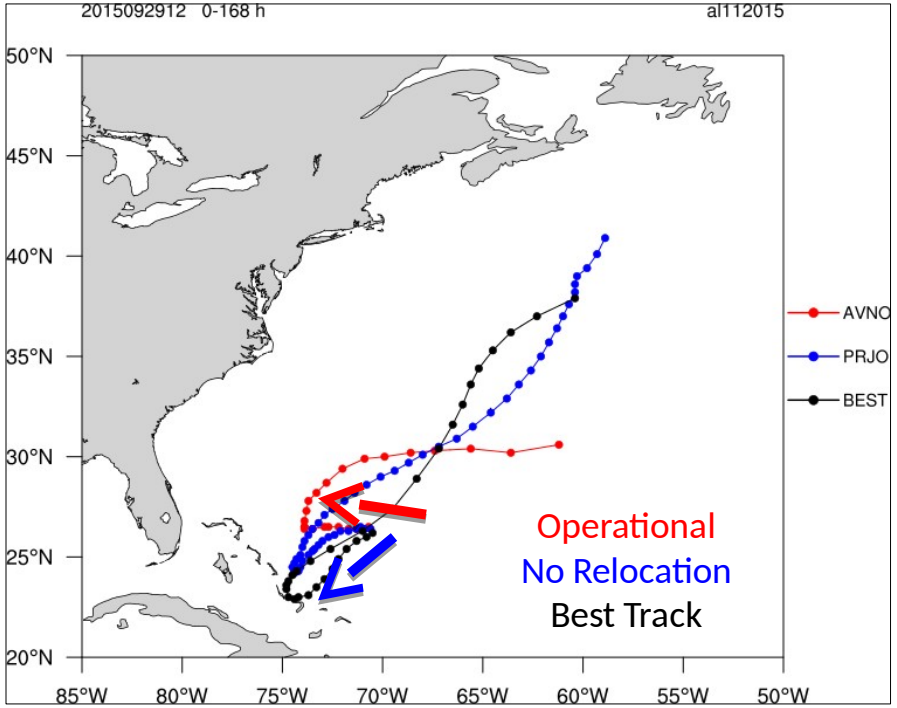
Joaquin Mean Track Errors w/ and w/out relocation



29 September 1200 UTC Cycle







Joaquin Summary and Next Steps

- Operational GFS/GDAS utilizes complex combination of bogusing, vortex relocation, and advisory minSLP assimilation for TC initialization

- However, case study reveals that current vortex relocation scheme detrimental to Joaquin forecasts
  - Post-genesis period: no-relocation run better captured SW movement
  - During intensification period, no-relocation run much better predicting eastward track (aside from one particular cycle)
  - After 2 October 0600 UTC, experiment and control similar

- Need more evaluation to better understand why

Longer Term Solutions

- Test more period(s) at operational resolution to quantify this sensitivity
  - This work was motivated by results of similar tests performed as part of hybrid DA development that showed similar results
  - If warranted, turn off relocation scheme in operations
- Fixes to relocation?
  - Apply on the model native grid
  - Filtering options
  - Only apply when distance exceeds (or is within) thresholds
- Alternatives within the data assimilation itself
  - Position assimilation directly in the hybrid-variational solver*
  - Position assimilation in the EnKF to improve covariance representation*
  - Feature Calibration and Alignment (FCA) in GSI*

Thanks!

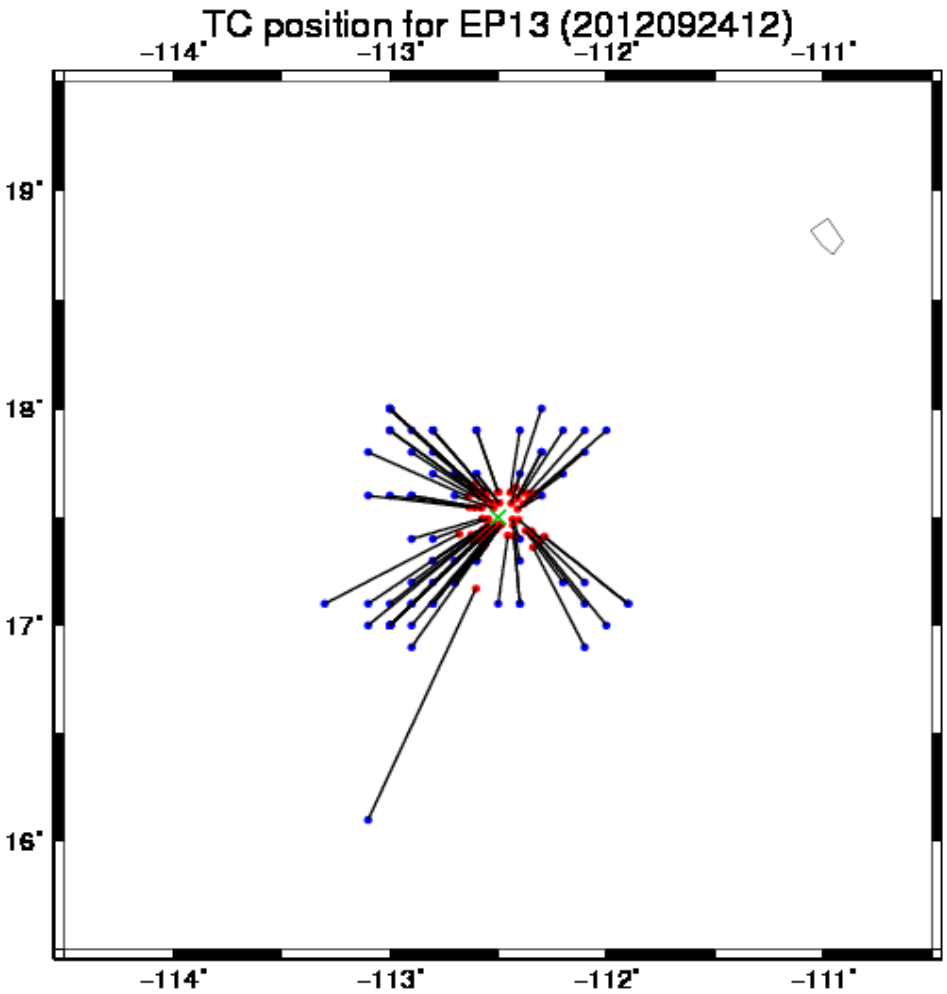
The first author is supported through NOAA/NWS R2O funding on grant NA15NWS4680017

Continuation of Work by Ota
Application of "Relocation" to EnKF

- TCs in EnKF ensemble used as part of EnVar solver can sometimes have issues do to lack of TC relocation
  - MinSLP assimilated in EnKF and EnVar, but relocation only in EnVar
- TC relocation of EnKF first guess ensemble has been proposed by Ota
  - Compromise of methods of position assimilation and mechanical relocation
- Algorithm already developed with preliminary tests completed.
  - Not yet implemented for technical reasons
- As part of R2O project, will resurrect and continue this development path
  - Has significant potential for position assimilation in EnVar through improved TC covariances
  - Implications for use of EnKF ensemble in GEFS as well

TC relocation to the EnKF ensembles (From Ota)

Apply TC relocation used in deterministic analysis to each ensemble member, but allowing TC structure perturbations and some TC position spread.

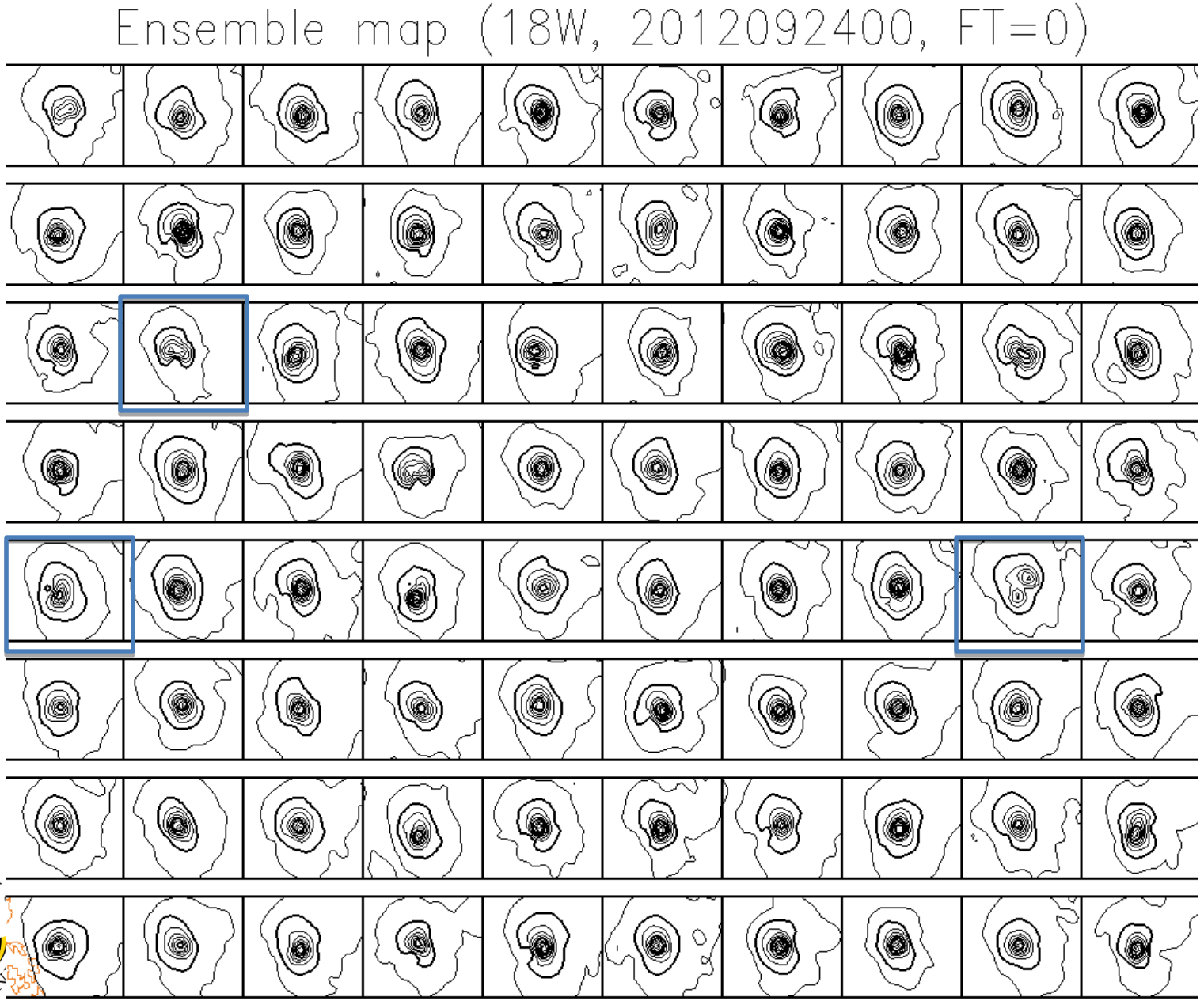


1. Update TC center position (latitude and longitude) by the EnKF
2. Use updated positions as inputs to the TC relocation
3. Apply this procedure before the EnKF analysis and GDAS analysis

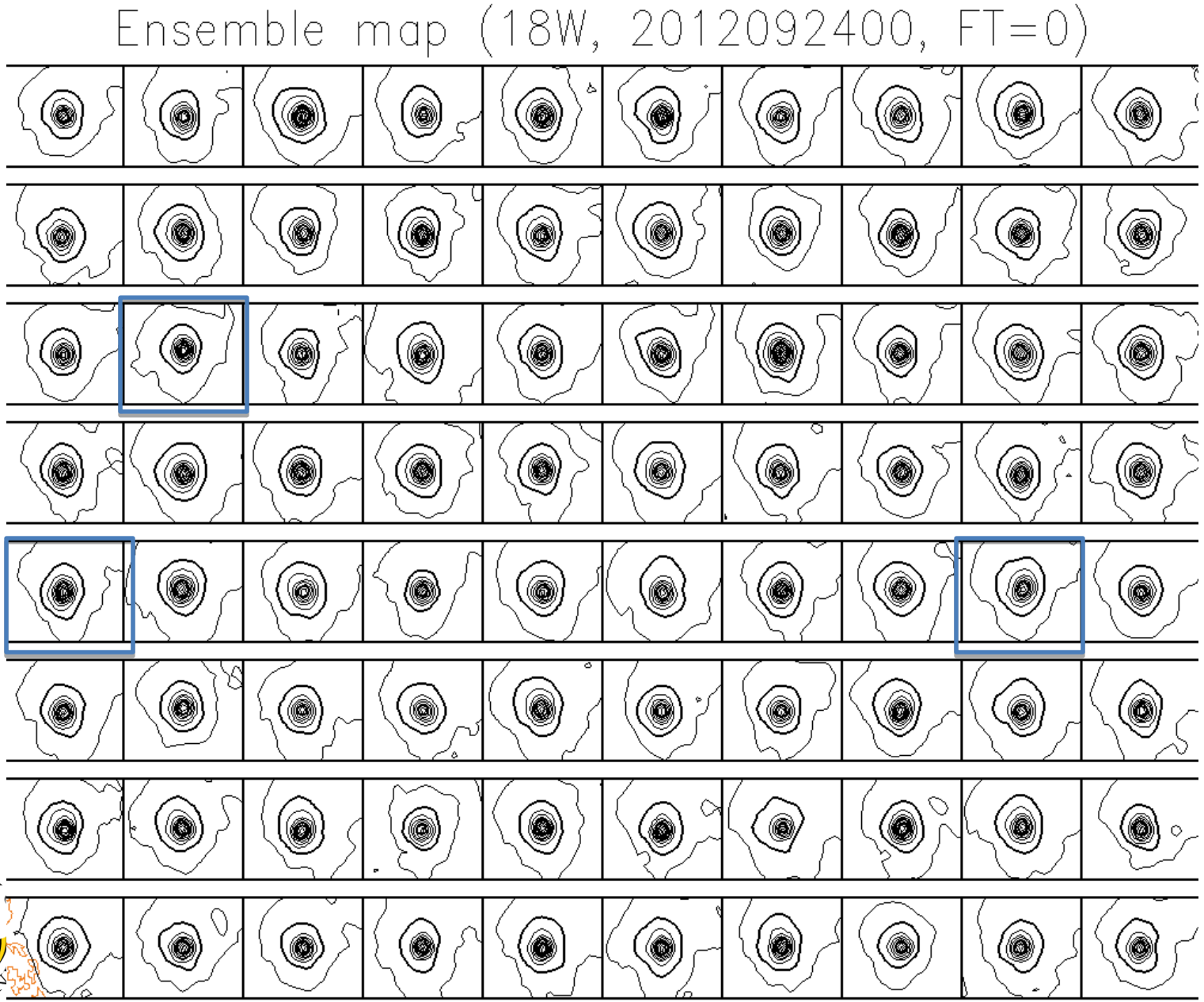
The idea is to separate linear problem (TC location space) and nonlinear problem (actual relocation of fields).

Blue: first guess position
Red: Updated position
Green: TC vital position

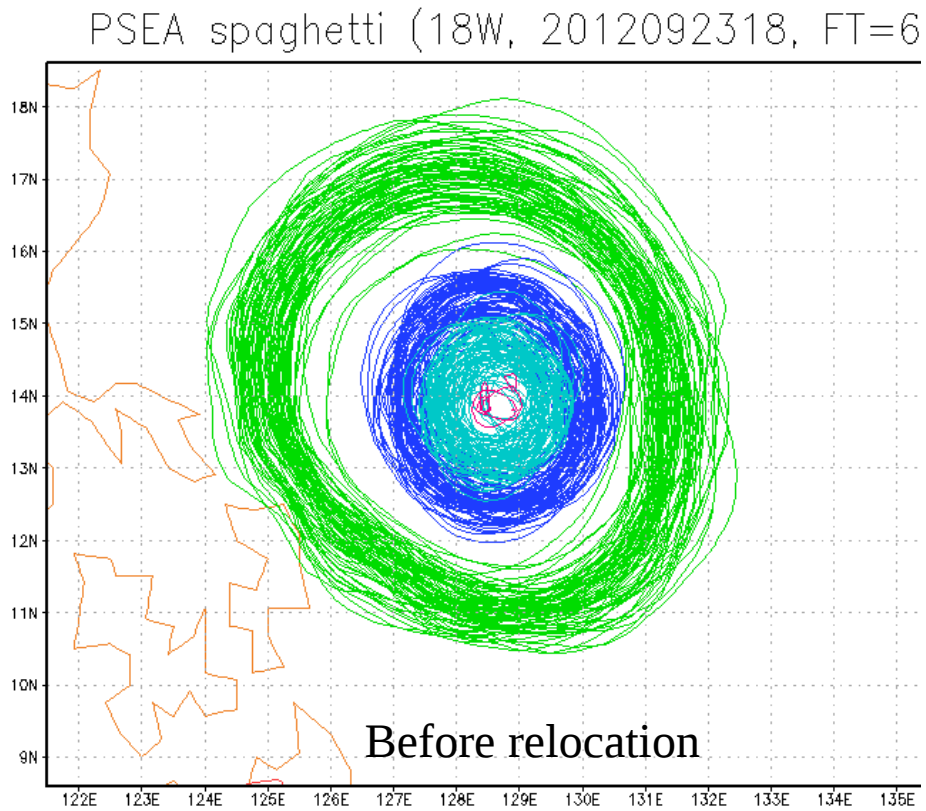
18W: 00UTC Sep. 24 EnKF analysis (no relocation)

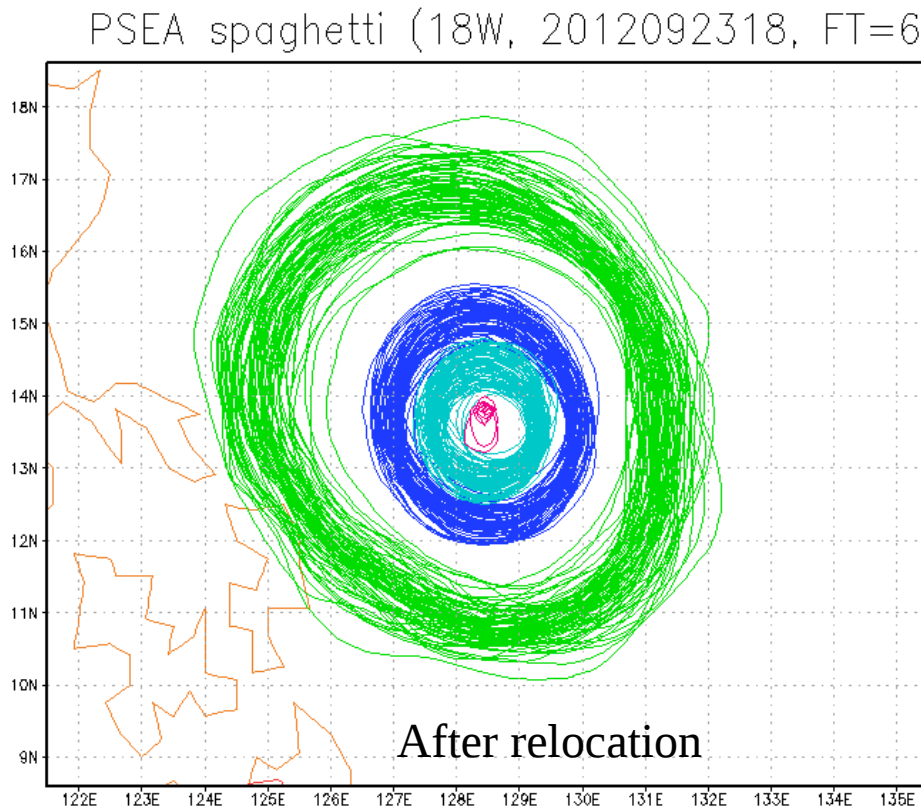


18W: 00UTC Sep. 24 EnKF analysis (with relocation)



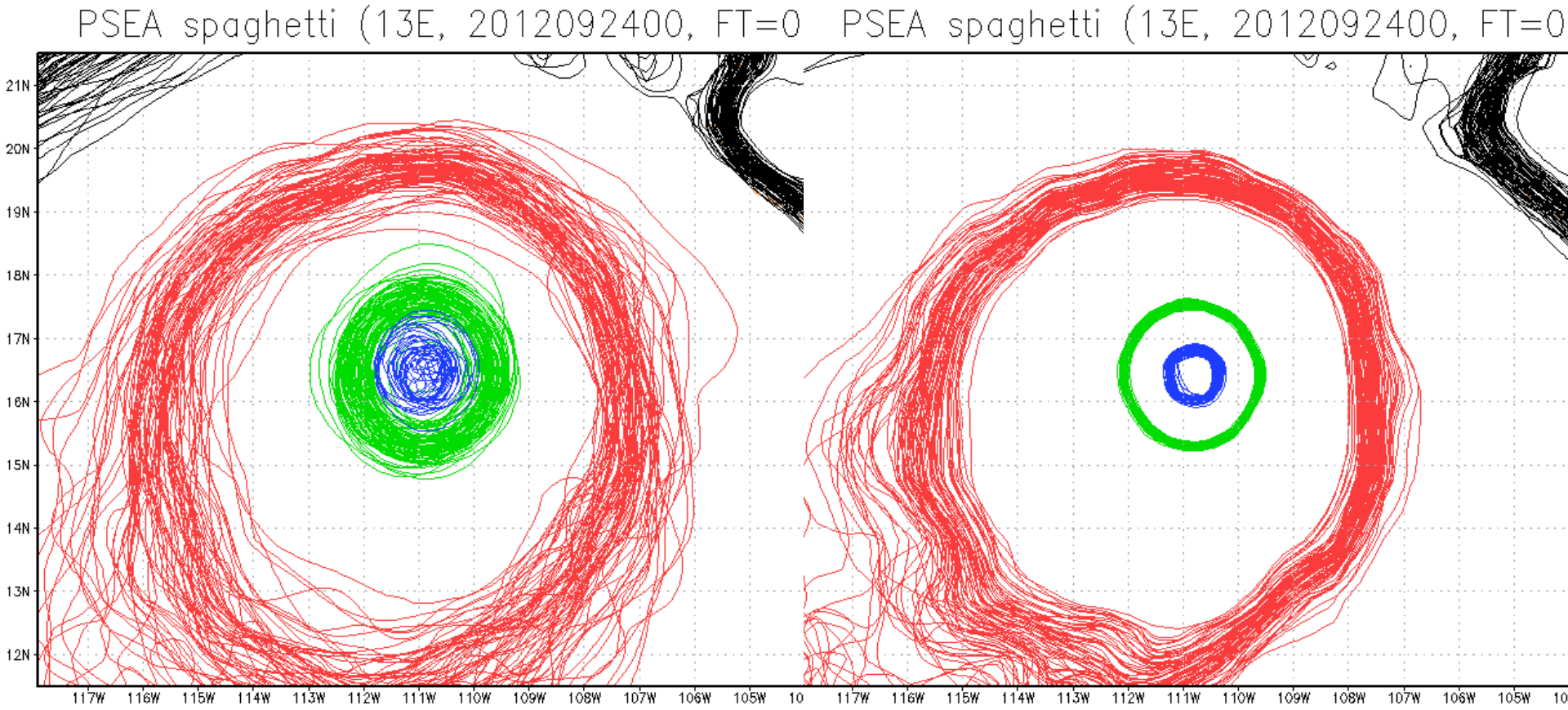
Example: spaghetti diagram
From Ota





TC relocation of this method can reduce the uncertainty on the TC position, maintaining the TC structure perturbations and some of the position uncertainty.

Comparison with GEFS TC relocation (from Ota)



EnKF analysis with TC relocation

EnKF 6 hour forecast perturbation + GEFS TC relocation

GEFS operational TC relocation scheme destroyed almost all initial position uncertainty and create very small spread around TC.